Compression Strength of Composite Primary Structural Components

Semiannual Status Report

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Performance Period: May 1, 1995 to October 31, 1995

NASA Grant NAG-1-537

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February, 1996

INTRODUCTION

Activities under this grant are concerned with analyses of composite material structures for aircraft. These analyses are conducted with the aim to better understand the fundamental mechanics of the response and failure of typical composite structures under static loads, and to develop special purpose codes to be used in parametric studies, or optimal design, for selected structural components. Two research activities are summarized in this report. The first is *Pressure Pillowing of an Orthogonally Stiffened Cylindrical Shell*, and the second is *Improved Solid-to-Shell Transition Elements*.

RESEARCH ACCOMPLISHED

Pressure Pillowing of an Orthogonally Stiffened Cylindrical Shell

The focus of the stiffened shell research is the effect of cabin pressurization on the stiffener-to-skin joint. The design of stiffener-to-skin joints is one of the major technology issues in utilizing graphite/epoxy composites in the fuselage of a large transport aircraft. The manner in which the loads are transferred in the stiffener-to-skin joints under internal pressurization is important for determining the load capacity of these joints. Analyses were developed to study the distribution of the interacting loads between the shell and stiffeners, and to study the pillowing of the shell, for a geometry and pressure typical of a large transport aircraft. Analyses are based on a structural repeating unit, or unit cell, of a periodically stiffened, infinite, circular cylindrical shell with closed ends. See Fig. 1. Primarily the aim is to understand the fundamental mechanics of the load transfer in the vicinity of the shell-ring-stringer joint. Secondly, these analyses can be used in parametric studies of joint response, and perhaps for design. A potential benefit of such an analysis/design capability is to use fewer expensive fasteners in the graphite/epoxy fuselage. Where fasteners are required in a graphite/epoxy structure, aluminium fasteners cannot be used because of galvanic corrosion to the metal. More expensive fasteners, like titanium, are required to avoid corrosion.

The research on the nonlinear response of the orhogonally stiffened shell subject to internal pressure was recently published, and the citation for it is

> Johnson, E.R., and Rastogi, N., "Interacting Loads in an Orthogonally Stiffened Composite Cylindrical Shell," **AIAA Journal,** Vol. 33, No.7, July, 1995, pp. 1319-1326.

A second paper on the effect of an asymmetric open section frame on the linear response was accepted in a peer-reviewed journal that does not have page limit restrictions, and a revised manuscript was submitted. The citation for it is

> Rastogi, N., and Johnson, E. R., "Analysis of an Internally Pressurized Othogonally Stiffened Cylindrical Shell with an Asymmetrical Section Ring," **Mechanics of Composite Materials and Structures**, accepted 10/31/95 and to appear.

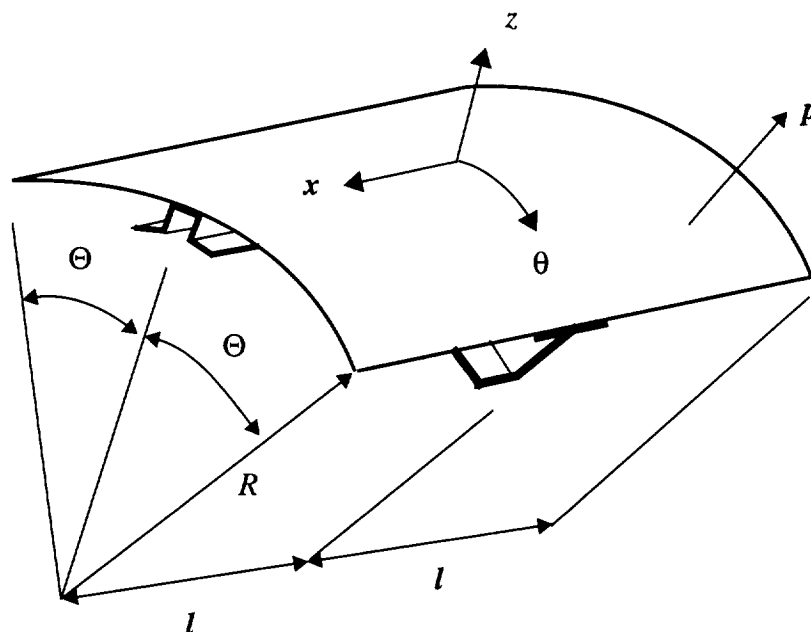Copies of these publications were given to the technical monitor.

Fig. 1   Structural repeating unit of an orthogonally stiffened cylindrical shell subjected to a internal pressure p.

Improved Solid-to-Shell Transition Elements

Transition finite elements permit a structural model to contain shell and solid elements in one model by having shell element degrees of freedom on one or more faces of the transition element, and solid element degrees of freedom on other faces. Thus, they are useful in global/local modeling schemes to reduce the number of degrees of freedom in the model and yet provide three-dimensional response information to the analyst.

The purpose of the transition finite element research is to eliminate artificial stress concentrations associated with transition element TR15. Element TR 15 was developed earlier under this grant, see Ref. 1. In particular, TR15 was developed for laminated composite material structures in order to determine interlaminar stresses for situations in which delamination is a important mode of damage/failure. TR15 elements connect twenty-node solid elements stacked through the thickness to a single eight-noded shell element. The stiffness matrix for TR15 was obtained by degenerating the stiffness matrix of the twenty-node solid element. The shell element nodes of TR15 do not have to lie on the element itself. Shell kinematics are used to degenerate the twenty node solid element, and as a result of the reaction to the undeformable normal assumption of shell theory, through-the-thickness normal stresses can occur as an unwelcome artifact in the transition element. These artificial through-the-thickness normal stresses can contaminate the response in adjacent solid elements, unless careful attention is paid to mesh refinement.

The alternative method of connecting solid to shell elements in a structural model is to use multi-point constraints (MPCs). Commercial finite element codes, like ABAQUS, provide the user with the multi-point constraint capability. However, if these codes were to have robust tran-

sition elements in their library of elements, the user will find them more convenient than MPCs. The reason for this is that stiffness matrix for the transition element is developed independent of the assembled structural model, and can be assembled using existing assembly procedures in the code. However, the use of MPCs require the user to write constraint equations *after* model assembly is complete, so that the user can identify the global degree of freedom numbers of those nodes which participate in the constraint equations. These constraint equations are then used to reduce the unrestrained structural stiffness matrix.

The modification made to TR15 is to include a thickness stretch term in the shell kinematics, even though the shell element does not represent this kinematic variable. Then, this additional kinematic degree of freedom is eliminated by static condensation. In the static condensation procedure, the action associated with this thickness stretch term in each transition element is not known, or represented, in the shell theory and hence is assumed to vanish. This modification of TR15 is denoted as TR15MOD1. Both elements TR15 and TR15MOD1 have the same number of degrees of freedom, which is fifty-one. (Note that the twenty node solid element has sixty degrees of freedom.)

To assess the performance of element TR15MOD1, several single element tests were done as well as tests on beam-type models consisting of an assemblage of elements. All of these test were conducted for mathematically two-dimensional problems assuming a linear elastic response. Single element tests consisted of extension, bending, and shear. The beam models were either subject to extension or pure bending. Details of the single element tests in extension are discussed in the next paragraph, but the details of the beam models are not presented here.

The extension tests for single element models are shown in Fig. 2. (Material properties used
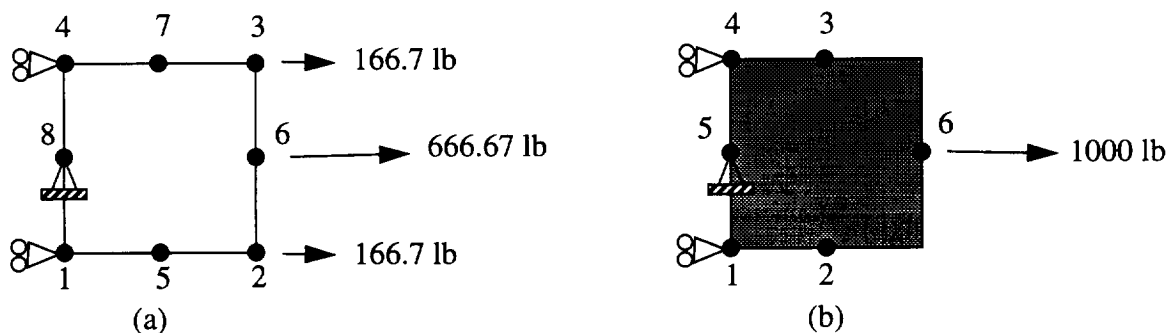

Fig. 2   Single element tests in extension. Element size is 1.0 in × 1.0 in. × 0.25 in. (a) Plane stress element CPS8 in ABAQUS, and (b) Transition element.

were a modulus of elasticity of 30×10^6 psi and a Poisson's ratio of 0.30.) Strain energy components for each test case are listed in Table 1. For this simple state of stress, only the strain energy component due to axial normal stress s_{11} is non-zero. Plane stress element CPS8 gives the exact solution in the sense of the arithmetic of finite precision, floating point numbers used by the computer. Strain energy components due to thickness normal stress s_{22} and transverse shear stress s_{12} in TR15 are substantially larger in magnitude than the corresponding values for element CPS8,

indicating that transition element TR15 is in error in predicting through-the-thickness stress components. Transition element TR15MOD1 shows improved response with respect to TR15 in the sense that strain energy components due to normal stress s_{22} and shear stress s_{12} are much smaller.

Table 1: Strain energy components for the single element tests under extension.

Element	Strain energy components in inch-pounds.			Total strain energy in inch-pounds
	Due normal stress to s_{11}	Due to normal stress s_{22}	Due to shear stress s_{12}	
Plane stress[a]	6.6665×10^{-2}	8.5877×10^{-19}	2.0676×10^{-30}	6.6665×10^{-2}
Transition element TR15	6.5416×10^{-2}	-4.2714×10^{-4}	4.2716×10^{-4}	6.5416×10^{-2}
Transition element TR15MOD1	6.6665×10^{-2}	1.0989×10^{-7}	1.1218×10^{-12}	6.6665×10^{-2}

a. Element CPS8 in the ABAQUS (Version 5.4) finite element code.

In summary, the conclusions from the single element tests and beam tests are:

• TR15MOD1 shows improved response with respect to TR15 for extensional loading as measured by the strain energy components that should vanish.

• TR15MOD1 and TR15 give the same results in bending for the single element tests, and in bending for the beam model tests when there is only one row of elements through the beam thickness.

• TR15MOD1 gives slightly improved performance with respect to TR15 for the beam models subject to bending when two rows of elements through the thickness of the beam are used.

• TR15MOD1 and TR15 give the same results in pure shear, which coincide with the results of the plane stress element.

Reference

1. Dávila, C. G., and Johnson, E. R., "Delamination Initiation in Postbuckled Dropped-ply Laminates," Center for Composite Materials and Structures, Virginia Polytechnic Institute. and State University., Blacksburg, VA 24061, Report. CCMS-91-24 and VPI-E-91-23, December 1991, pp. 32-88.